10/583399
AP3 Rec'd PCT/PTO 16 JUN 2006

STEEL WIRE FOR COLD FORGING HAVING EXCELLENT LOW TEMPERATURE IMPACT PROPERTIES AND METHOD OF PRODUCING SAME

Technical Field

[0001] The present invention relates to a steel wire or bar (hereinafter, referred to as "steel wire") which is used as a material for bolts, shafts and PC steel bars for construction applied to parts for machine structures having relatively high strength. More particularly, the present invention pertains to a steel wire for cold forging, which is capable of being applied to cold forging and cold form rolling processes and has improved low temperature toughness in use, thereby assuring excellent low temperature impact properties, and a method of producing the same.

Background Art

[0002] A spheroidized material and non-heat treated steel are known as conventional steel for cold plastic working. When the spheroidized material is used to produce final goods, such as bolts, it is problematic in that it is must be additionally quenched/tempered to assure tensile strength as desirable properties required after a cold forging process, complicating the production, resulting in increased production costs.

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[0003] With respect to non-heat treated steel, the use of non-heat treated steel has increased in automobiles and industrial machine parts mostly in Japan and Europe since it was developed in the middle of the 1970's. A design of an alloy is properly conducted and cooling and rolling conditions are controlled during hot rolling in ironworks to adjust the structure of a material. Thereby, it is possible to conduct a cold forging process while assuring high strength without subsequent heat treatments (quenching/tempering). Accordingly, the non-heat treated steel has advantages of a simplified process and a reduced production cost.

[0004] A representative example of the non-heat treated steel is disclosed in Japanese Pat. Laid-Open Publication No. Sho. 59-136420, in which the content of manganese is high and a small amount of vanadium as a precipitation hardening element is added to typical carbon steel for machine structures to precipitate the small amount of carbonitride in a ferrite matrix structure during a cooling process after hot forging. Thereby, strength increases, and consequently, it is possible to omit subsequent quenching/tempering processes. However, the above non-heat treated steel is disadvantageous in that since cold formability and cuttability are poor, it is an unsuitable material for cold working.

[0005] With respect to another example of non-heat treated steel, Japanese Pat. Laid-Open Publication No. Hei. 7-54940 discloses a technology of producing a bolt. In the technology, in the course of producing parts having a specific shape through a cold forging process after a hot wire rod is rolled, carbon content is reduced to improve cold workability, a small amount of niobium is added to improve strength and toughness due to the formation of a fine microstructure, and a heat treatment is conducted during a cooling process after hot rolling. However, the bolt produced by this non-heat treated steel is disadvantageous in that since it has an undesirable life in use in an environment in which tensile and compressive stresses are repeatedly axially applied, it is unsuitable for parts for automobiles.

[0006] Yet another example of the conventional non-heat treated steel is disclosed in U.S. Pat. No. 5,554,233, in which when billets containing reinforcement elements for increasing strength are subjected to sequential hot forging and controlled cooling processes to form wire rods, grains of austenite are made fine during a final hot forging process, thereby forming a fine bainite structure during a subsequent cooling process. The non-heat treated steel of the above patent is characterized in that strength and toughness increase due to the fine bainite structure, it is unnecessary to

conduct an additional heat treatment process during a cold forging process to produce the bolt, and the steel has remaining compressive stress.

[0007] The above patent discloses that impact absorption energy is about 10 J/cm^2 at -40ºC in view of low temperature toughness.

[0008] Meanwhile, parts, which are used in devices or automobiles in severely cold regions or polar regions, require a material having excellent low temperature impact toughness. However, conventional non-heat treated steel including the steel of the above patent have insufficient low temperature impact toughness, and thus, there remains a need to develop novel steel having excellent low temperature impact properties.

Disclosure of the Invention

[0009] Accordingly, the present invention has been made keeping in mind the disadvantages and problems of conventional steel for cold forging, and an object of the present invention is to provide a steel wire for cold forging, which has significantly improved low temperature toughness in use, thereby assuring excellent low temperature impact absorption energy, and a method of producing the same.

Brief Description of the Drawings

[0010] The above and other objects, features and other advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

[0011] FIG. 1 is a graph showing low temperature impact absorption energy at -40ºC as a function of a tempering parameter according to the present invention; and

[0012] FIG. 2 is a histogram showing low temperature impact absorption energies at -40ºC for the 9T level of bolts produced using materials of the present invention, spheroidized materials and non-heat treated steels.

Best Mode for Carrying Out the Invention

[0013] The present inventor has conducted extensive studies and repeated tests into development of novel steel to accomplish the object of the present invention, resulting in the following finding. When a steel wire is subjected to an impact test at a low temperature (-40ºC), it can be seen that the steel wire has excellent low temperature impact absorption energy in comparison

with that produced through a conventional method (quenching/tempering processes after a spheroidizing process). A method of producing the steel wire comprises rapidly heating typical carbon steel for machine structures, which is capable of being quenched, to an Ac3 transformation point or higher to limit an austenite grain size to 5 - 20ºC, quenching the heated steel in water or oil, and tempering the quenched steel under tempering conditions such that tensile strength is 70 - 130 kgf/mm^2 at a tempering parameter (P) ranging from 21,800 to 30,000, which is defined by the following Equation 1.

Equation 1

$$P = 1.8 \times (T + 273) \times (14.44 + \log t)$$

wherein, T is a tempering temperature (ºC), and t is a tempering time (sec).

[0014] In other words, the present invention is characterized in that if a material is tempered under tempering conditions such that tensile strength is 70 - 130 kgf/mm^2 at a tempering parameter ranging from 21,800 to 30,000 while the material is quenched so that an austenite grain size is made extremely fine in the range of 5 - 20ºC, the resulting material has Charpy impact absorption energy of 60 J/cm^2 or more at a low temperature of -40ºC even though it has

high strength, and consequently, the material has excellent impact properties in comparison with conventional steel.

[0015] Among steels for machine structures, steel containing specific components must be properly quenched and tempered so as to produce steel having the above characteristics according to the present invention. With respect to this, the chemical composition and heat treatment of the steel, which are required to produce the steel according to the present invention, are as follows.

[0016] The steel according to the present invention mostly consists of C-Si-Mn components including 0.10 - 0.40 wt% C, 1.0 wt% or less of Si, 0.30 - 2.0 wt% Mn, and the balance of Fe and impurities. If necessary, the steel may further comprise at least one component selected from the group consisting of 0.05 - 2.0 wt% Cr, 0.05 - 1.5 wt% Mo, and 0.0003 - 0.0050 wt% B. The reason why ranges of the components are limited is as follows.

C: 0.10 - 0.40 wt%

[0017] C is the most important element essential to improve strength during a quenching process, and generates carbides to increase strength. However, it is one of the strong alloy elements negatively affecting notch toughness, that is, it increases an impact transition temperature and reduces fracture energy. When the content

of C is less than 0.10 wt%, a hardening effect by the quenching is insignificant, and when the content is more than 0.40 wt%, a lot of carbide is precipitated, causing reduction of impact toughness.

Si: 1.0 wt% or less

[0018] Si is an element used to achieve deoxidation of the steel, and causes solid-solution hardening to improve strength. When the content of Si is more than 1.0 wt%, since a great amount of Si is solid-solved in carbide precipitate, movement of carbon is hindered during a tempering process, interrupting spheroidizing of carbide, resulting in reduced impact toughness. Accordingly, it is necessary to limit the content to 1.0 wt% or less.

Mn: 0.30 - 2.0 wt%

[0019] Mn is an element for solid-solution hardening, and is used to prevent reduction of impact toughness caused by use of an excessive amount of C and Si and to supplement reduction in strength of steel having low C and Si content. To accomplish these, it is necessary to use Mn in an amount of at least 0.30 wt%. However, if Mn is used in an excessive amount, toughness and deformation resistance increase. Therefore, the Mn content must not exceed 2.0 wt%.

Cr: 0.05 - 2.0 wt%

[0020] Cr is an element used to improve strength, quenching hardness, and toughness. When the content of Cr is less than 0.05 wt%, improvement of the above physical properties is insignificant. When

the content is more than 2.0 wt%, economic efficiency is reduced because Cr is relatively expensive. Accordingly, the lower and upper limits of the Cr content are set to 0.05 wt% and 2.0 wt%, respectively.

Mo: 0.05 - 1.5 wt%

[0021] The effect caused by use of Mo is almost the same as that of Cr. When the content of Mo is less than 0.05 wt%, insufficient results are assured. When the content is more than 1.5 wt%, since deformation resistance with respect to cold working increases, the content is set to 1.5 wt% or less.

B: 0.0003 - 0.0050 wt%

[0022] B is an element for improving hardenability. When the content of B is less than 0.0003 wt%, the effect of B is insignificant. On the other hand, when the content is more than 0.0050 wt%, hardenability is reduced. Meanwhile, B may be combined with N in a structure in use to form BN, causing grain boundary embrittlement. Accordingly, typically, 0.01 - 0.05 wt% Ti having an affinity with N, which is stronger than B, is added in conjunction with B to increase the effect caused by the use of B. Additionally, it is preferable to add one or more of Zr, Nb, or Al that act equally with Ti.

[0023] P and S are unavoidable impurities of steel. They cause grain boundary segregation during a tempering process, thereby reducing impact toughness. Furthermore, they reduce a deformation ratio during a cold working process. Thus, it is necessary to limit the content of each of them to 0.030 wt% or less within possible limits.

[0024] The present inventor has conducted extensive studies into the method of producing steel of the present invention using steel having the above composition, resulting in the finding that, in a steel material which is quenched/tempered, an austenite grain size and tempering conditions (a distribution state and a shape of precipitated carbides, a ratio of ferrite or the like) are very important as factors affecting low temperature impact absorption energy.

[0025] In the method of the present invention, the reason why the austenite grain size after a quenching process is limited to 5 - 20 μm is as follows. Through repeated tests, it can be confirmed that impact toughness is remarkably decreased at a low temperature of -40ºC when the size is more than 20 μm, and that it is difficult to produce grains having a size of less than 5 μm through typical quenching/tempering processes.

[0026] When producing a quenched/tempered steel wire which has excellent impact absorption energy at a low temperature (-40ºC) according to the present invention, the reason why the tempering conditions are limited so that the parameter of Equation 1 ranges from 21,800 to 30,000 is as follows.

[0027] The present inventor drew JIS G 4105 SCM420 and JIS G 4051 S22C wire rods having a diameter of 15 mm so that the wire rods each had a diameter of 13.7 mm, rapidly heated the drawn wires to a Ac3 point or higher so that an austenite grain size was 8 – 14 μm, quenched the heated wires in water or oil, and tempered the quenched wires with changing the tempering parameter by controlling a heating temperature and a heating time within a tensile strength range of 70 - 130 kgf/mm^2. Additionally, the resulting steel wires were subjected to a V-notch specimen and a Charpy impact test at -40ºC. The results are shown in FIG. 1.

[0028] As shown in FIG. 1, when the tempering parameter was 21,800 - 30,000, impact absorption energy was 60 J/cm^2 or more at -40ºC.

[0029] In this regard, the reason why the impact absorption energy is limited to 60 J/cm^2 or more is that when an SCM435 spheroidized material is cold forged, quenched and tempered to produce a

conventional high tensile bolt, impact absorption energy is about 60 J/cm^2 at -40ºC.

[0030] The tempering parameter of 21,800 - 30,000 may be assured by properly controlling the heating temperature, the heating time, the heating rate etc. of the quenching and tempering processes within a desired range of tensile strength according to the components of the material.

[0031] Therefore, with respect to low temperature impact toughness of the quenched/tempered steel wire, if a quenched material having fine grains and proper compositions is tempered so that the tempering parameter of Equation 1 is 21,800 - 30,000, it is obvious that it is possible to produce steel wire having excellent impact absorption energy at a low temperature of -40ºC. Accordingly, it can be seen a very important factor in the course of producing the quenched/tempered steel wire having excellent low temperature impact properties.

[0032] A better understanding of the steel wire and its production method according to the present invention may be obtained through the following example which is set forth to illustrate, but is not to be construed as the limit of the present invention.

EXAMPLE

[0033] Having the chemical composition (wt%) shown in the following Table 1 and a diameter of 16 mm, a hot rolled wire rod was drawn so as to have a diameter of 14.7 mm, and then quenched/tempered using a high frequency induction heater which consists of sequential processes. At this stage, samples were produced while a heating temperature, a heating time and a heating rate were controlled to change a tempering parameter so that an austenite grain size was 5 - 20 μm and tensile strength was 70 - 140 kgf/mm^2.

TABLE 1

Sample	C	Si	Mn	P	S	Cr	Mo	B	Fe
1	0.15	0.92	0.62	0.010	0.009	-	-	-	Bal.
2	0.20	0.25	1.37	0.012	0.008	-	-	-	Bal.
3	0.21	0.23	0.95	0.012	0.007	-	-	0.0025	Bal.
4	0.21	0.25	0.73	0.013	0.011	1.03	-	-	Bal.
5	0.23	0.29	0.83	0.009	0.009	1.12	0.27	-	Bal.
6	0.35	0.97	0.75	0.010	0.009	0.97	0.22	-	Bal.

[0034] The samples, which were produced under the above conditions, were worked to form JIS Z 2202 No. 4 test pieces (V-notch, 10 mm X 10 mm), and the pieces were subjected to a Charpy impact test at a low temperature of -40ºC according to JIS Z 2242 to calculate impact absorption energy. The results are described in the following Table 2.

TABLE 2

Samples		Tensile strength (kgf/mm^2)	Grain size (μm)	Tempering parameter	Impact absorption energy (J/cm^2)
Sample 1	Exam.1	73.2	8.2	27320	181.9
	Exam.2	102.2	12.3	22568	88.3
	CO.EX.1	109.8	14.1	21010	36.5
	CO.EX.2	95.4	23.7	24150	51.6
Sample 2	Exam.3	75.3	16.4	29074	120.7
	Exam.4	105.7	16.2	22165	71.4
	CO.EX.3	89.6	11.2	30850	32.5
	CO.EX.4	90.7	27.5	25140	50.8
Sample 3	CO.EX.5	123.8	13.5	19550	25.3
	Exam.5	91.3	10.6	28266	198.5
	CO.EX.6	84.6	11.2	30742	43.4
	CO.EX.7	82.9	35.0	27990	58.8
Sample 4	Exam.6	117.9	10.9	22456	69.8
	Exam.7	93.2	12.1	27351	179.8
	CO.EX.8	102.5	11.2	30728	48.9
	CO.EX.9	127.3	12.6	21668	53.2
Sample 5	Exam.8	87.4	13.2	29550	91.6
	Exam.9	128.1	11.6	22070	69.3
	CO.EX.10	132.9	10.9	21000	50.5
	CO.EX.11	120.3	26.8	25630	51.7
Sample 6	CO.EX.12	135.4	14.5	21532	55.8
	Exam.10	101.2	13.7	28465	181.6
	Exam.11	95.9	6.4	29680	70.5
	CO.EX.13	98.7	10.5	30742	56.3

Exam. = Example Co.Ex. = Comparative example

[0035] From Table 2, it can be seen that when the samples of the present invention are heat treated so that the austenite grain size is 5 - 20 μm and the tempering parameter is 21,800 - 30,000, the samples have excellent impact absorption energy of 60 J/cm^2 or more at a low temperature of -40ºC, thereby assuring excellent low temperature impact toughness. Furthermore, it can be seen that impact absorption energy values may be significantly different from each other if the austenite grain sizes or the tempering parameters

are different from each other even though tensile strengths are the same as each other.

[0036] Additionally, in order to prove superiority of the present invention, the 9T level of bolts were produced according to JIS standards using materials of the present invention and conventional spheroidized materials and non-heat treated steels, and test pieces were sampled from the bolts. The test pieces were worked at -40ºC so as to have V notches, thereby forming standard pieces having a size of 10 mm X 10 mm. The standard pieces were subjected to a Charpy impact test, and test results were compared to each other. The test results are shown in FIG. 2.

[0037] At this stage, the 9T level of wire rods, which were produced using SCM 420 (JIS G 4105) as the material of the present invention according to the method of the present invention, were subjected to cold forging and form rolling processes to produce the bolts. As for the conventional spheroidized materials, which were spheroidized by heating SCM 435 (JIS G 4105) at 760ºC for 6 hours according to a conventional method, were subjected to cold forging and form rolling processes and quenched/tempered to produce the 9T level of bolts. In regard to the conventional non-heat treated steels, when billets containing SMn433 (JIS G 4106) components were hot rolled into wire

rods, controlled hot rolling and cooling processes were conducted to make structures fine to produce non-heat treated steels having the 9T level of tensile strength. The resulting non-heat treated steels were subjected to cold forging and form rolling processes to produce bolts.

[0038] From the results of FIG. 2, it can be seen that a bolt produced using the material of the present invention has excellent impact toughness in comparison with a bolt employing the conventional spheroidized materials or non-heat treated steels.

Industrial Applicability

[0039] As described above, steel of the present invention has excellent low temperature impact absorption energy that is about 3.7 times as high as a conventional material and about 20 times as high as conventional non-heat treated steel at a low temperature of -40ºC.

Claims

C1. A steel wire for cold forging, which has excellent low temperature impact properties, comprising 0.10 - 0.40 wt% C, 1.0 wt% or less of Si, 0.30 - 2.0 wt% Mn, 0.03 wt% or less of P, 0.03 wt% or less of S, and a balance of Fe and impurities, wherein an austenite grain size is 5 - 20 μm, impact absorption energy is 60 J/cm^2 or more at -40ºC, and tensile strength is 70 - 130 kgf/mm^2.

C2. The steel wire as set forth in claim 1, further comprising at least one component selected from the group consisting of 0.05 - 2.0 wt% Cr, 0.05 - 1.5 wt% Mo, and 0.0003 - 0.0050 wt% B.

C3. A method of producing a steel wire for cold forging, which has excellent low temperature impact properties, comprising:

rapidly heating steel, which contains 0.10 - 0.40 wt% C, 1.0 wt% or less of Si, 0.30 - 2.0 wt% Mn, 0.03 wt% or less of P, 0.03 wt% or less of S, and a balance of Fe and

impurities, to a Ac3 transformation point or higher so that an austenite grain size is 5 - 20 μm;

cooling the heated steel; and

heat treating the cooled steel in such a way that tensile strength is 70 - 130 kgf/mm^2 at a tempering parameter (P) ranging from 21,800 to 30,000, which is expressed by a following Equation 1, so that impact absorption energy is 60 J/cm^2 or more at -40ºC,

Equation 1

$$P = 1.8 \times (T + 273) \times (14.44 + \log t)$$

wherein, T is a tempering temperature (ºC), and t is a tempering time (sec).

C4. The method as set forth in claim 3, wherein the steel further comprises at least one component selected from the group consisting of 0.05 - 2.0 wt% Cr, 0.05 - 1.5 wt% Mo, and 0.0003 - 0.0050 wt% B.

STEEL WIRE FOR COLD FORGING HAVING EXCELLENT LOW TEMPERATURE IMPACT PROPERTIES AND METHOD OF PRODUCING SAME

Abstract

[0040] Disclosed is a steel wire for cold forging, which has excellent low temperature impact properties, and a method of producing the same. The steel wire consists of 0.10 - 0.40 wt% C, 1.0 wt% or less of Si, 0.30 - 2.0 wt% Mn, 0.03 wt% or less of P, 0.03 wt% or less of S, and the balance of Fe and impurities. The steel wire has an austenite grain size of 5 - 20 μm, impact absorption energy of 60 J/cm^2 or more at -40ºC, and tensile strength of 70 - 130 kgf/mm^2. A steel material for cold forming according to the present invention has impact toughness that is greatly superior to a conventional spheroidized material or non-heat treated steel at a low temperature of -40ºC.

Fig. 1

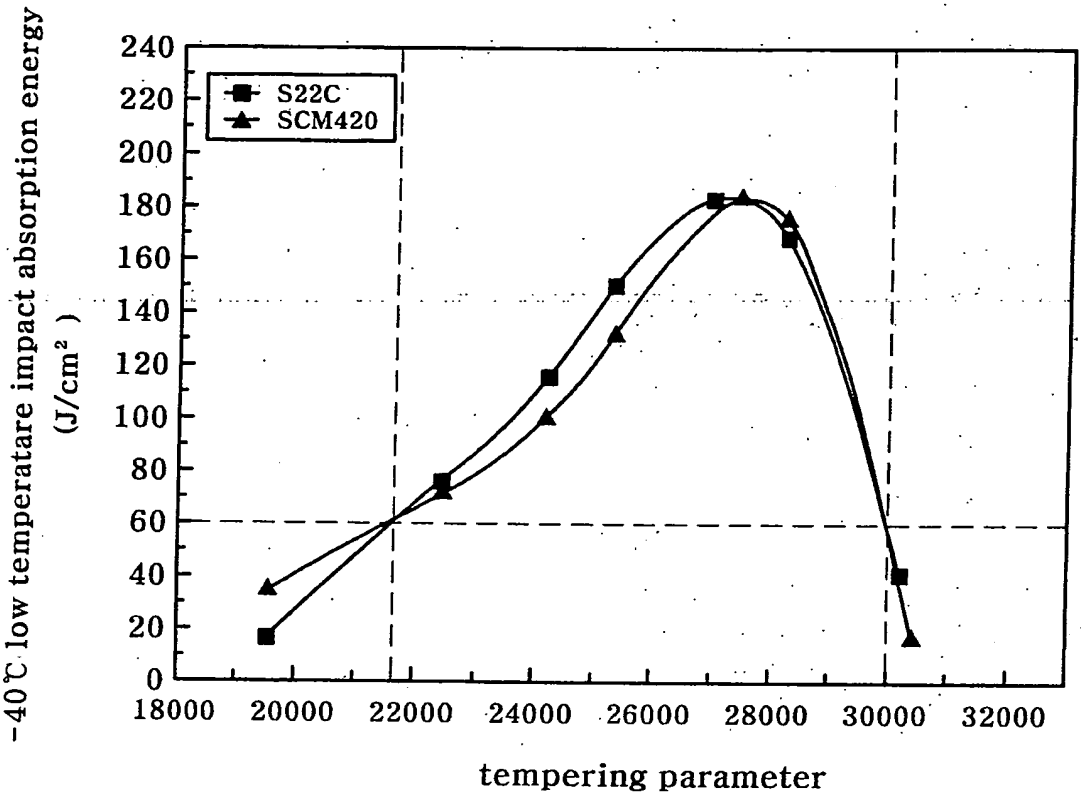
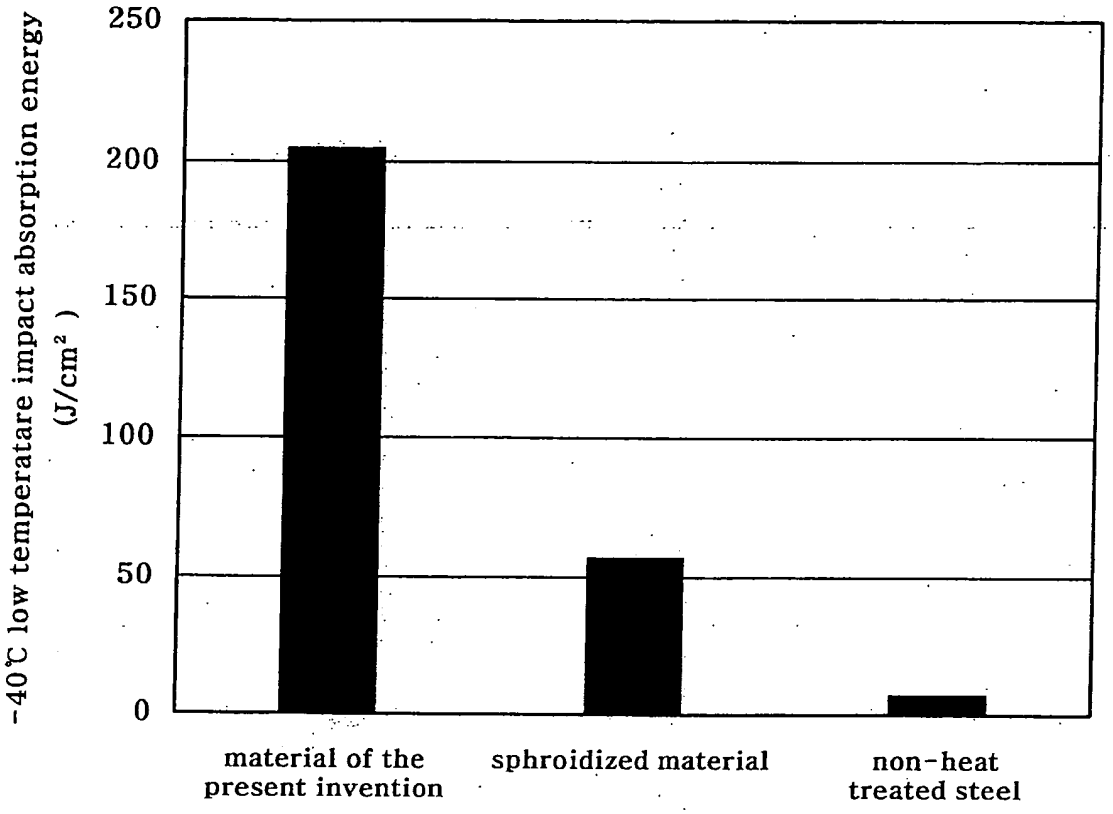

-40℃ low temperatare impact absorption energy (J/cm²)
240
220
200
180
160
140
120
100
80
60
40
20
0
S22C
SCM420
18000
20000
22000
24000
26000
28000
30000
32000
tempering parameter

Fig. 2


-40℃ low temperatare impact absorption energy (J/cm²)
250
200
150
100
50
0
material of the present invention
sphroidized material
non-heat treated steel

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